



Nicolaou, M., Doufexi, A., & Armour, SMD. (2008). A selective cluster index scheduling method in OFDMA. In *IEEE 68th Vehicular Technology Conference (VTC Fall 2008), Calgary* (pp. 1 - 5). Institute of Electrical and Electronics Engineers (IEEE).
<https://doi.org/10.1109/VETECF.2008.460>

Peer reviewed version

Link to published version (if available):
[10.1109/VETECF.2008.460](https://doi.org/10.1109/VETECF.2008.460)

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A Selective Cluster Index Scheduling Method in OFDMA

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Introduction

- OFDM is an attractive method for future wireless communications due to its robustness to dispersion in multipath environments.
- OFDMA supports multiple users on the same channel by joint exploitation of temporal and frequency fading resulting in higher diversity order and consequently higher downlink rates.
- Exploitation of Multiuser Diversity requires knowledge of instantaneous channel conditions from Mobile Stations at the Base Station via a feedback channel.
- A Channel Quality Indicator (CQI) is used to determine instantaneous channel condition for every frequency subcarrier.

I. Feedback Overhead Implications at Vehicular Speeds with Conventional Channel State Information in OFDMA

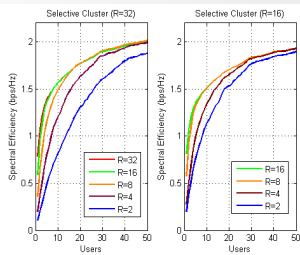
- Most commonly used CQI metric is the instantaneous Signal to Noise Ratio (SNR).
- A scheduler exploiting Multiuser Diversity is required to have access to Channel State Information (CSI), at least at the rate at which the channel is changing, i.e. depends on the coherence time of the channel.
- The channel coherence time depends on the speed of the Mobile Stations. Hence for high vehicular speeds, higher feedback overhead conveying CSI is required.
- Due to the requirement of SNR knowledge across the frequency domain, for OFDMA systems exploiting Multiuser Diversity, overall capacity quickly reaches bottleneck point, at which the entire uplink channel is occupied with feedback information.

| SPEED (KM/H) | DOPPLER SPECTRUM 802.16 | |
|-----------------|-----------------------------------|---|
| | Channel Coherence time (ms) | Number of OFDMA symbol durations assuming a CP of 1/8 |
| 20 | 6.4795 | 57.8295 |
| 60 | 2.1600 | 19.2780 |
| 120 | 1.0800 | 9.6390 |
| 180 | 0.7200 | 6.4260 |
| 240 | 0.5400 | 4.8195 |
| 280 | 0.4629 | 4.1314 |

- Several techniques aimed at reducing feedback overhead have been proposed, with varying tradeoff levels between feedback overhead reduction and spectral efficiency.
- Most notable feedback reduction techniques consider adjacent subcarrier grouping (clustering) and Selective Multiuser Diversity (SMUD).

II. Feedback Reduction by Clustering and Selective Cluster Transmission

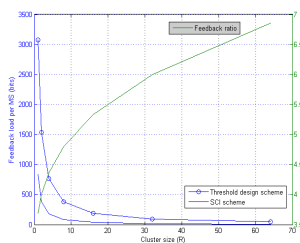
- Adjacent frequency subcarriers can be treated as a single feedback unit, considering the average SNR of these subcarriers as CQI.
- Provided that the correlation of these adjacent subcarriers is high, only minor throughput degradations are observed. Subcarrier correlation is depended on the rms delay spread of the channel (τ_{rms}).
- For a specified τ_{rms} , a cluster size R giving best tradeoff between feedback overhead reduction and downlink throughput degradation exists.
- The optimum cluster size reduces as τ_{rms} increases, thus limiting the possibility of further feedback reduction. Provided N being the total number of subcarriers, the number of generated clusters is given by: $D=N/R$.
- A scheduler employing Multiuser Diversity does not schedule user on weak clusters. Hence, CSI for weak clusters conveys redundant information, due to the limited probability of resource allocation on these clusters.
- Selective Cluster transmission limits the number of clusters each Mobile Station is allowed to request resources only on its S strongest clusters for each OFDM symbol.
- Provided B is the number of bits representing quantised SNR (typically 5-6, but reaching 30 with coding) the total number of CSI per user on each OFDM symbol is: $S[B+\log_2(D)]$.



- Spectral usage defines the ratio of allocated clusters over the total number of clusters, as a function of the number of users: $U = U_i/D$
- U_k defined as: $U_k = \frac{1}{D} \sum_{i=1}^S U_i$
- As spectral usage converges to 1, selective cluster scheme converges to full feedback scheme.
- Convergence achieved for a high number of users and/or high large number of eligible fed back clusters.
- Both requirements increase uplink feedback overhead.

III. Selective Cluster Index (SCI) for Channel Quality Indicator

- For the selective cluster scheme replace SNR with only the **index** of the S strongest clusters of each user. Elimination of SNR feedback can achieve major feedback overhead reductions.



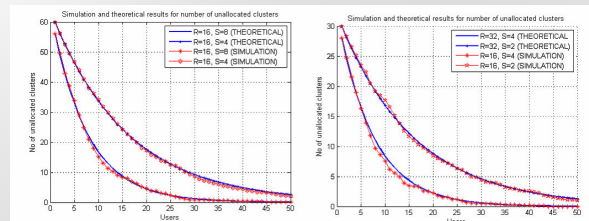
- Comparison of feedback overhead for SCI scheme with a threshold based feedback scheme shows improved savings in uplink feedback overhead.
- The Base Station has no knowledge of instantaneous channel conditions on the frequency subchannels.
- Resource allocation is performed through a random selection process amongst users identified as eligible for current cluster.
- Loss in spectral efficiency is expected due to the randomness in the allocation process

Conclusions

- OFDMA systems exploiting Multiuser Diversity impose heavy uplink feedback requirements. At high vehicular speeds, the rate at which feedback is required at the Base Station increases, mitigates diversity gains and results in a bottleneck point in link performance.
- This paper suggests the introduction of a new channel quality metric that has a reduced load. Signal to Noise Ratio (SNR) is replaced by a relative channel strength metric given by the cluster index of the strongest clusters of each user.
- The use of this new metric results in a new scheduling policy, that involves random resource allocations amongst eligible users. By tolerating a certain cluster outage probability, not only the uplink feedback requirements reduce, but also the strong user identification process at the Base Station becomes more efficient, allowing for increased downlink rates.
- The proposed Selective Cluster Index scheme has shown strong resilience to high vehicular speeds due to the reduced uplink overhead, allowing Multiuser Diversity to be exploited at much higher speeds than an SNR based feedback scheme.

IV. Implications of cluster outage probability

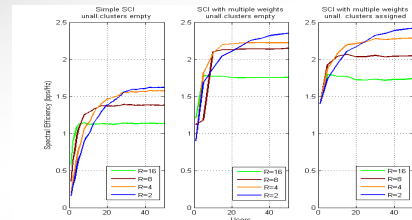
- Any selective scheduling policy introduces an uncertainty on spectral usage.
- Define cluster outage probability as the probability of a cluster not being identified as eligible for resource allocation by any of the K users, feeding back CSI for their S strongest clusters.
- Cluster outage probability: $P_{out}=D-U_k$. Expected value of U_k : $E[U_k] = \sum_{u=S}^D u P_k(u-S)$
- $P_k(i)$: the ith element of vector P_k containing the stacked, non-zero probabilities of the number of fed back cluster indices, when k users are active.
- Simulation results confirm theoretical results for expected cluster outage probability.



- For the Selective Cluster Index scheme, it is important to fine tune the expected cluster outage probability in order to achieve the best throughput and feedback reduction performance.
- Unlike existing selective cluster schemes relying on SNR feedback, SCI does not converge to a full SNR based feedback scheme with minimization of cluster outage due to the nature of channel quality metric (cluster index).
- Increased selectivity at the Base Station is achieved by reducing the number of fed back clusters per user (S), i.e. by tolerating a non-zero cluster outage probability.
- Higher spectral efficiency by reducing the amount of uplink feedback information.

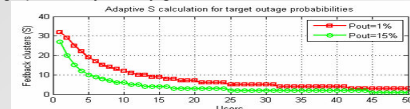
V. Performance Enhancements for Selective Cluster Index via Multiple Weighting Vector Transmission

- Random assignment of clusters in outage improves fairness and average system throughput. It also shifts higher the maximum tolerable cluster outage for rate maximisation by further reduction in feedback parameters.
- The use of multiple weighting vectors in Opportunistic Beamforming increases spectral efficiency even with omission of SNR feedback. Adaptive use of vectors for feedback overhead constrain.

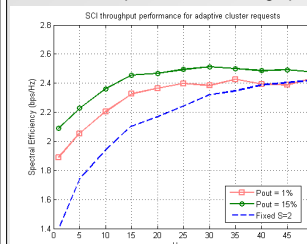


VI. Adaptive Cluster Request for fixed cluster outage probability

- Variations in downlink performance observed for different numbers of fed back clusters S for changing number of users, due to change in cluster outage probability.
- The Base Station can request a variable number of fed back clusters from each Mobile Station, depending on the number of available users in the system, in order to maintain an (approximately) fixed cluster outage probability for any given number of active users.



- Compare the performance of the Selective Cluster Index Scheme with adaptive cluster request for two different expected cluster outage probabilities and a variable cluster outage scheme (fixed S).



- Variations in rate growth are attributed to the discrete nature of S, giving variations of the actual cluster outage probability with the target one.
- Reducing the cluster size, i.e. increasing the number of available clusters returns a more accurate cluster outage at the expense of increasing feedback load.
- The adaptive cluster request method gives better performance for a range of active users.
- A cluster outage probability of 15% returns higher throughput than that of 1% as it allows the Base Station to better identify strong users.
- An optimum cluster outage probability exists, that achieves the best tradeoff between good selectivity and random cluster allocation